

We claim:

1. An interlace-to-progressive scan conversion system, comprising:
a prefilter having a prefiltered signal as an output;
a motion estimator having the prefiltered signal as input and a motion-corrected signal as an output;
an adaptive filter having the prefiltered signal and the motion-corrected signal as inputs.
2. The interlace-to-progressive scan conversion system of claim 1, wherein the prefilter is a line averaging filter.
3. The interlace-to-progressive scan conversion system of claim 2, wherein the prefilter is a spatial line averaging filter.
4. The interlace-to-progressive scan conversion system of claim 1, wherein the motion estimator is adapted to perform a 3-D recursive search.
5. The interlace-to-progressive scan conversion system of claim 1, wherein the motion estimator is adapted to perform motion vector correction.
6. The interlace-to-progressive scan conversion system of claim 1, wherein the motion estimator is adapted to perform a block erosion process.

7. The interlace-to-progressive scan conversion system of claim 1, wherein the adaptive filter comprises a median filter.

8. The interlace-to-progressive scan conversion system of claim 1, wherein the adaptive filter comprises a line averaging filter.

9. The interlace-to-progressive scan conversion system of claim 1, wherein the adaptive filter comprises an adaptive recursive filter.

10. The interlace-to-progressive scan conversion system of claim 1, wherein the adaptive filter comprises a time recursive filter.

11. The interlace-to-progressive scan conversion system of claim 1, wherein:
the adaptive filter comprises a three-stage adaptive recursive filter, wherein:

- a first stage comprises a function that selects between using static pixels data and moving pixels data from a next field;
- a second stage comprises a function that selects a more valid set of data between motion compensated data from a previous field and the pixels selected by the first stage; and
- a third stage comprises a function that combines an intra-field interpolation with the more valid set of data selected by the second stage.

12. The interlace-to-progressive scan conversion system of claim 11, wherein the prefilter comprises a spatial line average filter.
13. The interlace-to-progressive scan conversion system of claim 11, wherein the motion estimator comprises a 3-D recursive search sub-component.
14. The interlace-to-progressive scan conversion system of claim 11, wherein the motion estimator comprises a motion vector correction sub-component.
15. The interlace-to-progressive scan conversion system of claim 11, wherein the motion estimator comprises a block erosion sub-component.
16. An interlace-to-progressive scan conversion system, comprising:
a spatial line averaging prefilter having a prefiltered signal as an output;
a motion estimator having the prefiltered signal as input and a motion-corrected signal as an output, the motion estimator comprising:
a 3-D recursive search sub-component;
a motion vector correction sub-component;
a block erosion sub-component;
a three-stage adaptive recursive filter, wherein:
a first stage comprises a function that selects between using static pixels data and moving pixels data from a next field;

a second stage comprises a function that selects a more valid set of data between motion compensated data from a previous field and the pixels selected by the first stage; and

a third stage comprises a function that combines an intra-field interpolation with the more valid set of data selected by the second stage.

17. The interlace-to-progressive scan conversion system of claim 16, wherein the 3-D recursive search sub-component resolves motion vectors to at least quarter-pixel accuracy.

18. The interlace-to-progressive scan conversion system of claim 17, wherein the look-up table consists of:

$$US_n = \left\{ \begin{pmatrix} 0 \\ 0 \end{pmatrix}, \begin{pmatrix} 0 \\ 1 \end{pmatrix}, \begin{pmatrix} 0 \\ -1 \end{pmatrix}, \begin{pmatrix} 1 \\ 0 \end{pmatrix}, \begin{pmatrix} -1 \\ 0 \end{pmatrix}, \begin{pmatrix} 0 \\ 2 \end{pmatrix}, \begin{pmatrix} 0 \\ -2 \end{pmatrix}, \begin{pmatrix} 3 \\ 0 \end{pmatrix}, \begin{pmatrix} -3 \\ 0 \end{pmatrix}, \begin{pmatrix} 0 \\ \frac{1}{4} \end{pmatrix}, \begin{pmatrix} 0 \\ -\frac{1}{4} \end{pmatrix}, \begin{pmatrix} \frac{1}{4} \\ 0 \end{pmatrix}, \begin{pmatrix} -\frac{1}{4} \\ 0 \end{pmatrix} \right\}$$

19. The interlace-to-progressive scan conversion system of claim 16, wherein the motion estimator includes a bilinear interpolator.

20. The interlace-to-progressive scan conversion system of claim 19, wherein a value of a first estimator is set to a value of a second estimator if:

$$e(\overline{MV}_a, \bar{X} - \overline{SMV}_{a,t}) > e(\overline{MV}_b, \bar{X} - \overline{SMV}_{b,t}) + Th$$

and wherein the value of the second estimator is set to the value of the first estimator if:

$$e(\overline{MV}_b, \overline{X} - \overline{SMV}_b, t) > e(\overline{MV}_a, \overline{X} - \overline{SMV}_a, t) + Th$$

where Th is a fixed threshold.

21. The interlace-to-progressive scan conversion system of claim 16, wherein an error function of the motion estimator includes penalties related to a length of the difference vector between a given candidate vector and a plurality of neighboring vectors.

22. The interlace-to-progressive scan conversion system of claim 21, wherein the error function is defined by:

$$e(\overline{C}, x, y, t) = \sum_{x \in B(x, y, t)} |F(x, y, t) - F(x - C_x, y - C_y, t - T)| + \alpha \cdot \|\overline{U}(x, y, t)\|$$

23. The interlace-to-progressive scan conversion system of claim 21, wherein the motion estimator assumes that a motion vector for an object between a previous field and a current field is the same as a motion vector for the object between the current field and a next field.

24. The interlace-to-progressive scan conversion system of claim 23, wherein a motion vector error correction function is defined by:

$$\overline{MV}(x, y, t) = \begin{cases} \begin{pmatrix} 0 \\ 0 \end{pmatrix}, & (e_m(x, y, t) \geq e_s(x, y, t)) \\ \overline{MV}(x, y, t), & (e_m(x, y, t) < e_s(x, y, t)) \end{cases}$$

where:

$$e_m(x, y, t) = \frac{\sum_{x \in X} |F(X) - F(C)| + \sum_{x \in X} |F(X) - F(D)|}{2}$$

$$e_s(x, y, t) = \frac{\sum_{x \in X} |F(X) - F(A)| + \sum_{x \in X} |F(X) - F(B)|}{2}$$

and where A , B , C , D , and X are blocks containing ends of candidate motion vectors, X being in the current field, A and C being in the previous field, and B and D being in the next field.

25. The interlace-to-progressive scan conversion system of claim 23, wherein a motion vector error correction function is defined by:

$$\overline{MV}(x, y, t) = \begin{cases} \begin{pmatrix} 0 \\ 0 \end{pmatrix}, & (e_m(x, y, t) \geq e_s(x, y, t)) \\ \overline{MV}(x, y, t), & (e_m(x, y, t) < e_s(x, y, t)) \end{cases}$$

where:

$$e_m(x, y, t) = \sum |F(C) - F(D)|$$

$$e_s(x, y, t) = \sum |F(A) - F(B)|$$

and where A , B , C , D , and X are blocks containing ends of candidate motion vectors, X being in the current field, A and C being in the previous field, and B and D being in the next field.

26. The interlace-to-progressive scan conversion system of claim 16, wherein a cost function is defined by:

$\forall F(x, y, t) \in B(x, y, t):$

$$D = |F(x, y, t) - F(x - MV_x, y - MV_y, t - 1)|$$

$$TD = TD + D$$

$$Diff = D - EstErr$$

$$EstErr = EstErr + (\delta + Diff);$$

$$Dev = Dev + \delta(|Diff| - Dev)$$

27. The interlace-to-progressive scan conversion system of claim 16, wherein the block erosion sub-component divides each block according to:

$$B(x, y, t) = \{(x, y) | X_x - X/2 \leq x \leq X_x + X/2 \wedge X_y - Y/2 \leq y \leq X_y + Y/2\}$$

wherein a vector $\overline{MV}(x, y, t)$ is assigned, into four sub-blocks $B_{i,j}(x, y, t)$

$$B_{i,j}(x, y, t) = \left\{ (x, y) | X_x - (1-i) \cdot \frac{X}{4} \leq x \leq X_x + (1+i) \cdot \frac{X}{4} \wedge X_y - (1-j) \cdot \frac{Y}{4} \leq y \leq X_y + (1+j) \cdot \frac{Y}{4} \right\}$$

and wherein the variables i and j take the values $+1$ and -1 ; wherein a vector $MV_{i,j}(x, y, t)$ is assigned to the pixels of each of the sub-blocks $B_{i,j}(x, y, t)$:

$$\forall (x, y) \in B_{i,j}(x, y, t) : \overline{MV}_{i,j}(x, y, t) = \overline{MV}_{i,j}(\bar{X}, t)$$

wherein:

$$\overline{MV}_{i,j}(\bar{X}, t) = \text{med}[\overline{MV}(x + i \cdot X, y, t), \overline{MV}(\bar{X}, t), \overline{MV}(x, y + j \cdot Y, t)]$$

wherein the median function is a median on the x and y vector components separately; and

wherein a resulting vector is replaced by an original motion vector unless the resulting vector is equal to one of the three input vectors.

28. The interlace-to-progressive scan conversion system of claim 16, wherein the first stage selection function is given by:

$$F_n(x, y, t) = \begin{cases} F(x + MV_x(x, y, t), y + MV_y(x, y, t), t + 1), & (D_m < D_s) \\ F(x, y, t + 1), & (D_m \geq D_s) \end{cases}$$

where:

$$D_s = \sum_{k=-2}^2 C_v(k) \cdot |F(x, y + k, t) - F(x, y + k, t + 1)|$$

$$D_m = \sum_{k=-2}^2 C_v(k) \cdot |F(x, y + k, t) - F(x - MV_x(x, y, t), y - MV_y(x, y, t) + k, t + 1)|$$

29. The interlace-to-progressive scan conversion system of claim 16, wherein the third stage combining function is given by:

$$F_o(x, y, t) = \begin{cases} F(x, y, t), & (y \bmod 2 = t \bmod 2) \\ (c_i \cdot F_i(x, y, t) + (1 - c_i)(c_p \cdot F_p(x, y, t) + (1 - c_p)F_n(x, y, t))), & (\text{otherwise}) \end{cases}$$

wherein c_i and c_p are adaptive coefficients ranging from 0 to 1; F_n is given by:

$$F_n(x, y, t) = \begin{cases} F(x + MV_x(x, y, t), y + MV_y(x, y, t), t + 1), & (D_m < D_s) \\ F(x, y, t + 1), & (D_m \geq D_s) \end{cases}$$

wherein intra-field interpolation is given by:

$$F_i(x, y, t) = \frac{F(x, y - 1, t) + F(x, y + 1, t)}{2}$$

and wherein backward data prediction is given by:

$$F_p(x, y, t) = F(x - MV_x(x, y, t), y - MV_y(x, y, t), t - 1)$$

30. An interlace-to-progressive scan conversion system, comprising:
- a spatial line averaging prefilter having a prefiltered signal as an output;
 - a motion estimator having the prefiltered signal as input and a motion-corrected signal as an output, the motion estimator comprising:
 - a 3-D recursive search sub-component having a bilinear interpolator;
 - a motion vector correction sub-component having an error function, the error function including penalties related to a length of the difference vector between a given candidate vector and a plurality of neighboring vectors;
 - a block erosion sub-component;
 - wherein the motion estimator assumes that a motion vector for an object between a previous field and a current field is the same as a motion vector for the object between the current field and a next field
 - a three-stage adaptive recursive filter having the prefiltered output and the motion-corrected output as inputs, the three stages comprising:
 - a first stage that comprises a function that selects between using static pixels data and moving pixels data from a next field;
 - a second stage that comprises a function that selects a more valid set of data between motion compensated data from a previous field and the pixels selected by the first stage; and

a third stage that comprises a function that combines an intra-field interpolation with the more valid set of data selected by the second stage.

31. An interlace-to-progressive scan conversion system, comprising:
 a spatial line averaging prefilter having a prefiltered signal as an output;
 a motion estimator having the prefiltered signal as input and a motion-corrected signal as an output, the motion estimator comprising: a 3-D recursive search sub-component; a motion vector correction sub-component; and a block erosion sub-component;
 wherein:
 the 3-D recursive search sub-component includes a bilinear interpolator defined by:

$$F(x, y, t) = (yf \cdot xf \cdot F(xi, yi, t)) + (yf \cdot (1 - xf) \cdot F(xi + 1, yi, t)) + ((1 - yf) \cdot xf \cdot F(xi, yi + 1, t)) + ((1 - yf) \cdot (1 - xf) \cdot F(xi + 1, yi + 1, t))$$

where:

$$yf = \lfloor y \rfloor \quad xf = \lfloor x \rfloor$$

and:

$$yi = y - \lfloor y \rfloor \quad xi = x - \lfloor x \rfloor$$

and wherein a value of a first estimator is set to a value of a second estimator if:

$$e(\overline{MV}_a, \bar{X} - \overline{SMV}_a, t) > e(\overline{MV}_b, \bar{X} - \overline{SMV}_b, t) + Th$$

and wherein the value of the second estimator is set to the value of the first estimator

if:

$$e(\overline{MV}_b, \bar{X} - \overline{SMV}_b, t) > e(\overline{MV}_a, \bar{X} - \overline{SMV}_a, t) + Th$$

where Th is a fixed threshold;

the 3-D recursive search sub-component has a look-up table consisting of:

$$US_n = \left\{ \begin{pmatrix} 0 \\ 0 \end{pmatrix}, \begin{pmatrix} 0 \\ 1 \end{pmatrix}, \begin{pmatrix} 0 \\ -1 \end{pmatrix}, \begin{pmatrix} 1 \\ 0 \end{pmatrix}, \begin{pmatrix} -1 \\ 0 \end{pmatrix}, \begin{pmatrix} 0 \\ 2 \end{pmatrix}, \begin{pmatrix} 0 \\ -2 \end{pmatrix}, \begin{pmatrix} 3 \\ 0 \end{pmatrix}, \begin{pmatrix} -3 \\ 0 \end{pmatrix}, \begin{pmatrix} 0 \\ \frac{1}{4} \end{pmatrix}, \begin{pmatrix} 0 \\ -\frac{1}{4} \end{pmatrix}, \begin{pmatrix} 1 \\ 4 \end{pmatrix}, \begin{pmatrix} -1 \\ 4 \end{pmatrix} \right\}$$

a motion vector correction sub-component having an motion vector error correction

function defined by:

$$\overline{MV}(x, y, t) = \begin{cases} \begin{pmatrix} 0 \\ 0 \end{pmatrix}, & (e_m(x, y, t) \geq e_s(x, y, t)) \\ \overline{MV}(x, y, t), & (e_m(x, y, t) < e_s(x, y, t)) \end{cases}$$

where:

$$e_m(x, y, t) = \sum |F(C) - F(D)|$$

$$e_s(x, y, t) = \sum |F(A) - F(B)|$$

and where A, B, C, D , and X are blocks containing ends of candidate motion vectors, X being in the current field, A and C being in the previous field, and B and D being in the next field.

a block erosion sub-component that divides each block according to:

$$B(x, y, t) = \{(x, y) | X_x - X/2 \leq x \leq X_x + X/2 \wedge X_y - Y/2 \leq y \leq X_y + Y/2\}$$

wherein a vector $\overline{MV}(x, y, t)$ is assigned, into four sub-blocks $B_{i,j}(x, y, t)$

$$B_{i,j}(x, y, t) = \left\{ (x, y) | X_x - (1-i) \cdot \frac{X}{4} \leq x \leq X_x + (1+i) \cdot \frac{X}{4} \wedge X_y - (1-j) \cdot \frac{Y}{4} \leq y \leq X_y + (1+j) \cdot \frac{Y}{4} \right\}$$

and wherein the variables I and j take the values $+1$ and -1 ; wherein a vector $MV_{ij}(x, y, t)$ is assigned to the pixels of each of the sub-blocks $B_{ij}(x, y, t)$:

$$\forall(x, y) \in B_{i,j}(x, y, t) : \overline{MV}_{i,j}(x, y, t) = \overline{MV}_{i,j}(\bar{X}, t)$$

wherein:

$$\overline{MV}_{i,j}(\bar{X}, t) = \text{med}[\overline{MV}(x + i \cdot X, y, t), \overline{MV}(\bar{X}, t), \overline{MV}(x, y + j \cdot Y, t)]$$

wherein the median function is a median on the x and y vector components separately; and
wherein a resulting vector is replaced by an original motion vector unless the resulting vector is equal to one of the three input vectors.

a three-stage adaptive recursive filter having the prefiltered signal and motion-corrected

signals as output, the three stages comprising:

a first stage comprises a function that selects between using static pixels data and

moving pixels data from a next field according to the function:

$$F_n(x, y, t) = \begin{cases} F(x + MV_x(x, y, t), y + MV_y(x, y, t), t + 1), & (D_m < D_s) \\ F(x, y, t + 1), & (D_m \geq D_s) \end{cases}$$

where:

$$D_s = \sum_{k=-2}^2 C_v(k) \cdot |F(x, y + k, t) - F(x, y + k, t + 1)|$$

$$D_m = \sum_{k=-2}^2 C_v(k) \cdot |F(x, y + k, t) - F(x - MV_x(x, y, t), y - MV_y(x, y, t) + k, t + 1)|$$

a second stage comprises a function that selects a more valid set of data between motion compensated data from a previous field and the pixels selected by the first stage; and

a third stage comprises a function that combines an intra-field interpolation with the more valid set of data selected by the second stage according to the function:

$$F_o(x, y, t) = \begin{cases} F(x, y, t), & (y \bmod 2 = t \bmod 2) \\ (c_i \cdot F_i(x, y, t)) + (1 - c_i)(c_p \cdot F_p(x, y, t) + (1 - c_p)F_n(x, y, t)), & (\text{otherwise}) \end{cases}$$

wherein c_i and c_p are adaptive coefficients ranging from 0 to 1; F_n is given by:

$$F_n(x, y, t) = \begin{cases} F(x + MV_x(x, y, t), y + MV_y(x, y, t), t + 1), & (D_m < D_s) \\ F(x, y, t + 1), & (D_m \geq D_s) \end{cases}$$

wherein intra-field interpolation is given by:

$$F_i(x, y, t) = \frac{F(x, y - 1, t) + F(x, y + 1, t)}{2}$$

and wherein backward data prediction is given by:

$$F_p(x, y, t) = F(x - MV_x(x, y, t), y - MV_y(x, y, t), t - 1)$$

32. A method for converting an interlaced image to a progressive scan image, the method comprising:

providing an input signal corresponding to an image;

prefiltering the input signal with a spatial line averaging prefilter;

estimating motion in the image by:

performing a 3-D recursive search;

performing a motion vector correction;

performing a block erosion to reduce blockiness in the progressive scan image;

filtering the signal in three stages:

in the first stage selecting between using static pixels data and moving pixels data from a next field;

in the second stage selecting a more valid set of data between motion compensated data from a previous field and the pixels selected by the first stage; and

in the third stage combining an intra-field interpolation with the more valid set of data selected by the second stage.

33. A method for converting an interlaced image to a progressive scan image, the method comprising:

providing an input signal corresponding to an image;

prefiltering the input signal with a spatial line averaging prefilter;

estimating motion in the image by:

assuming that a motion vector for an object between a previous field and a current field is the same as a motion vector for the object between the current field and a next field;

performing a 3-D recursive search;

performing a motion vector correction in which the error function penalizes a candidate vector based on a length of a difference vector between the candidate vector and a plurality of neighboring vectors;

performing a block erosion to reduce blockiness in the progressive scan image;

filtering the signal in three stages:

in the first stage selecting between using static pixels data and moving pixels data
from a next field;

in the second stage selecting a more valid set of data between motion compensated data from a previous field and the pixels selected by the first stage; and

in the third stage combining an intra-field interpolation with the more valid set of data selected by the second stage.